Transactive Energy Systems Research, Development and Deployment Roadmap

Prepared by the

GridWise® Architecture Council

Final Version, December 2018

The GridWise Architecture Council was formed by the U.S. Department of Energy to promote and enable interoperability among the many entities that interact with the electric power system. This balanced team of industry representatives proposes principles for the development of interoperability concepts and standards. The Council provides industry guidance and tools that make it an available resource for smart grid implementations. In the spirit of advancing interoperability of an ecosystem of smart grid devices and systems, this document presents an overview of the Transactive Energy Roadmap. The roadmap itself considers drivers of change, triggers for transactive energy system deployment, and required infrastructure for deployment at scale. This document explains the organization and structure of the roadmap and is recommended reading before reading the roadmap itself. Please see the www.gridwiseac.org website for more products of the Council that may be of interest.

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Glossary[1]

ADMS	Advanced Distribution Management System
AMI	Advanced Metering Infrastructure
BEM(S)	Building Energy Management (System)
Congestion	Restriction of electricity flow over a line due to physical limitations
CVR	Conservation Voltage Reduction
Cyber-Physical System	Interacting digital, analog, physical, and human components engineered for function through integrated logic and physics
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
Deterministic	A model which, when given a particular input, will always produce the same output (no randomness)
DMS	Distribution Management System
DOE	U.S. Department of Energy
DOE	U.S. Department of Energy
DR	Demand Response
DSO	Distribution System Operator[2]
FERC	Federal Energy Regulatory Commission
IOU	Investor Owned Utility
ISO	Independent System Operator
LMP	Locational Marginal Price
MDM	Meter Data Management (System)
NARUC	National Association of Regulatory Utility Commissioners
Prosumer	A prosumer is a person (or entity) who both consumes and produces
PSC	Public Service Commission
PUC	Public Utility Commission
PV	Photo-Voltaic
RTO	Regional Transmission Operator
Stochastic	Stochastic optimization refers to the minimization (or maximization) of a function in the presence of randomness in the optimization process
T&D	Transmission and Distribution
TE(S)	Transactive Energy (System)
VVO	Volt-VAR Optimization
X2G	Anything to Grid

[1] This glossary also includes some terms not used in this Roadmap but which relate to other terms and which may be useful for the reader.

[2] There are a range of DSO models under consideration in the industry. In this Roadmap the DSO is the entity responsible for planning and operational functions associated with a distribution system that is modernized for high levels of DERs and handles the interface to the bulk system Transmission System Operator (TSO) at a locational marginal price (LMP) node or transmission-distribution substation.

Introduction

It has been said that if Thomas Edison could see the electric industry today he would recognize it as being much the same as 100 years ago, but that may not be the case for much longer. The century old paradigm of large scale generation and distribution is starting to change as renewable resources make more of an impact. New distributed devices, both consumer and utility-owned, impact the grid directly and also interact with each other. Preparation to integrate these new resources and technologies through consideration of operational and policy changes built around measured and effective choices has already started. For example, the industry is undergoing a fundamental shift from a "load following" paradigm, where central generation adjusted to varying demand, to a "supply following" paradigm, where responsive demand absorbs variable generation such as solar and wind. During the transition to a more highly distributed system, the industry can't afford to design purely for either extreme. A key to success is the use of technologies that support flexible coordination of centralized and distributed elements. One such approach is provided by transactive energy systems.

Transactive energy systems are systems of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter[3]. The broad definition allows us to recognize the existing use of transactive techniques in bulk energy markets and to also consider the how to enable new techniques that may be used in distribution systems, at the interface between transmission and distribution, and perhaps even more broadly.

The need for transactive energy systems is being driven by economic, technological and customer preference opportunities that were just beginning to exist five years ago. With today's enhanced performance and declining costs for many renewable energy sources and storage technologies being deployed, these increased uses of distributed energy resources are here to stay. Distribution systems were not designed for large scale deployment of distributed energy resources with potential power flows in multiple directions. Ad hoc arrangements have worked so far, but as the combined effects of changes often outside of regulatory and utility observation and control become significant, a more robust response to maintaining and enhancing safety, reliability, and resilience of distribution energy systems and markets is required.

Overview

The GWAC transactive energy roadmap outlines a vision and path forward to achieve deployment of transactive energy systems at-scale as an operational element of the electric

[3] Section 3.1, GridWise Transactive Energy Framework Version 1.0, PNNL-22946, January 2015 (http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf)

power system to facilitate the integration of distributed energy resources and dynamic end-uses such as connected buildings. It also considers the application of transactive energy systems for the coordination and control of end-uses, for example, in managing energy in buildings and campuses.

The roadmap considers drivers of change, triggers for transactive energy system deployment, and required infrastructure for deployment at scale. Gaps in technology and infrastructure that may require investment are identified.

The roadmap captures potential changes over time (Stages) and organizes them by business and technical Tracks. Within each Track it also groups potential changes into Swim Lanes that identify what it is that we hope to see, what it takes for this to occur, what we see as a result, and what these features do to add value.

Stages

The roadmap is based on considering what is required to support increasing levels of distributed energy resource penetration in electrical distribution systems. The roadmap considers the overall vision in three stages, depicted in Figure 1, primarily characterized by the level of market development around distributed energy resource (DER) penetration. These stage definitions facilitate the reader to determine what stage a given distribution system is in based on how its characteristics align with these definitions. One should note that there are implications for the relationship between the distribution utilities and the bulk power system, and given the regional nature of the bulk power system, all distribution utilities within a given region will not usually find themselves at the same stage.

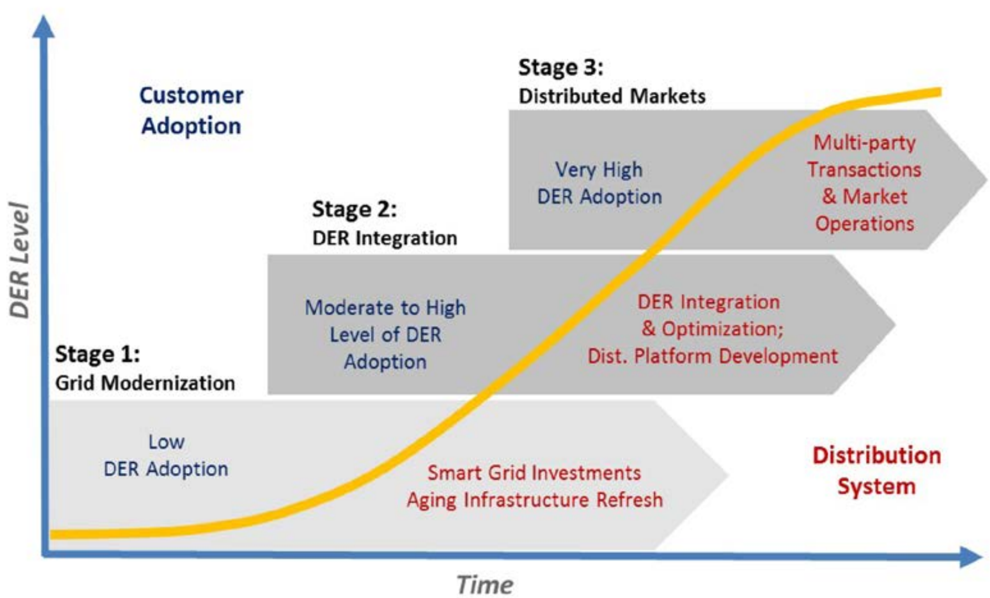

Figure 1: Distribution System Evolution[4]

Stage 1

In stage 1 there is limited DER penetration. DER value is administratively set (such as in net metering tariffs). DER has minimal but perceivable impact on distribution system operations. In the following sections this stage is characterized as "persistently demonstrated".

Stage 2

Levels of DER penetration grow as device prices continue to drop. Net metering tariffs begin to be replaced with market interactions that establish the value of the DER assets. Aggregated DER or large DER assets interact with bulk power markets based on a limited number of value streams. DER penetration has manageable impact on distribution system operations. In the following sections, this stage is characterized as "broadly applied".

Stage 3

DER penetration grows impacting distribution system operations and requiring new means for asset owners to realize return on investment. Combinations (stacks) of value streams are realized through DER participation in local, distribution level, markets. The stacked value streams have spatial and temporal variability reflecting operational needs in the distribution and bulk power systems. In the following sections, this stage is characterized as "at scale".

Roadmap Tracks

The roadmap tracks generally follow the GridWise Transactive Energy Framework's breakdown of considerations for transactive energy systems into the following four tracks:

Regulatory and Policy

This track describes the actions needed by regulators and other policy makers to enable Transactive Energy (TE) systems as envisioned in each of the three stages. The objective of the actions in this track is to establish an environment that enables transacting parties to understand rules of engagement and compensation in addition to performance requirements (and penalties for non-performance). The actions also focus on achieving a consistency of approach across jurisdictions as much as possible to promote interoperability. The actions described may be carried out by different policy-making bodies depending on the individual jurisdictions and types of utilities.

[4] LBNL-1003797, October 2015, Distribution Systems in a High Distributed Energy Resources Future: Planning, Market Design, Operation and Oversight

Many of the actions described in this track support development and implementation actions described in the following Business Models and Value Realization track, and to a limited extent, the actions included in the System Design and Architecture and Physical and Cyber Technologies and Infrastructure tracks.

Business Models and Value Realization

This track focuses on the various stakeholders, their roles in TE and how their business models need to evolve for them to provide and realize value in each of the three stages. While the regulatory and policy track describes the actions policymakers need to take to establish the needed TE environment, this track focuses on the actions to assess and implement needed business model changes by various stakeholder types, recognizing that business model changes include value propositions on both supply and demand sides.

System Design and Architecture

This track focuses on system design and architecture actions necessary to support each stage specifically dealing with information interoperability to support TE valuation, and operation and control aspects to understand and manage the impacts on the electric grid. This track depends on the business model to define required information exchange between TE parties in content and timing. This is where each stakeholder needs to develop or understand their "as-is" architecture and their "to-be" architecture, then develop a set of transitional states to get them there and transition between stages.

Physical and Cyber Technologies and Infrastructure

This track focuses on the changing Cyber-Physical needs and required actions through the progression of the three stages. This track addresses the technical layers of the GWAC Stack and the physical layers of the Control Abstraction Stack. It includes the activities aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electric grid. This track depends on the information exchange requirements considered in the system design and architecture track to ensure the ability to exchange information in support of transactions without detrimentally affecting the reliability of the electrical network.

Each of these areas is informed by the drivers for change such as increased penetration of rooftop solar, energy storage, electrification of transportation, etc.

Swim Lane Definitions

For each of the roadmap tracks, there is a separate table that describes the features of that track by each of the three stages. Also, for each stage there are four swim lanes that provide a more detailed breakdown of the features not only by stage but also by different perspectives. These perspectives are:

- **Vision** – what we hope to see at each stage
- **Enablers** – elements required if the Vision is to be realized
- **Results** – outcomes made possible by new patterns of use

- **Benefits –** how these outcomes add value (when compared with the status quo)

Organization of Material

In order to show the impact of changes based on the use of Tracks, Stages, and Swim Lanes, the roadmap is organized into sections based on Tracks. In addition to the Tracks mentioned above, the roadmap contains an additional Overview section which captures some of the key concepts from the other tracks. It provides an executive summary for the roadmap.

At the start of each section (except for the Overview), there is a list of three to five main concepts that were considered important to see represented in the section. These core concepts state the fundamental concept in as timeless (stage free) manner as possible so that one can then apply the concept by stating how it manifests through the stages. These manifestations are documented in tables. Also included in the core concepts are condensed encapsulations of the transactive energy principles described in Section 3.3 of the GWAC TE Framework

Within each section there are four tables, one for each swim lane. The tables consist of multiple rows of information. Each row of information captures something that represents a change or evolution occurring over time with three columns to describe what is seen in stages 1, 2, and 3 as the examples below show.

Vision what we hope to see at each stage	**Stage 1** Persistently Demonstrated	**Stage 2** Broadly Applied	**Stage 3** At Scale
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

Enablers elements required if the Vision is to be realized	**Stage 1** Persistently Demonstrated	**Stage 2** Broadly Applied	**Stage 3** At Scale
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

Results outcomes made possible by new patterns of use	**Stage 1** Persistently Demonstrated	**Stage 2** Broadly Applied	**Stage 3** At Scale
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

Benefits how these outcomes add value	**Stage 1** Persistently Demonstrated	**Stage 2** Broadly Applied	**Stage 3** At Scale
	Early scenario 1	Mid scenario 1	Late scenario 1
	Early scenario 2	Mid scenario 2	Late scenario 2
	Early scenario 3	Mid scenario 3	Late scenario 3

The core concepts provide a means to check for gaps (where a concept has not been invoked) or duplication (where a concept has been used multiple times). Although the core concepts provide a basis for verifying the completeness of the initial draft of the roadmap, multiple invocations of concepts are inevitable in cases where different rows have different scope but some overlap.

Core Concepts

Each section in this roadmap includes relevant core concepts (also described in Appendix A) which state the fundamental concepts in as timeless (stage-free) a manner as possible for each track of the roadmap. **Note**: items in ***bolded italics*** represent condensed encapsulations of the TE principles described in Section 3.3 of the TE Framework document[5].

Questions to Bear in Mind

It may be helpful for readers to consider the following questions based on the core concepts as this document is being read. These, or other interrogatives may help to make some of the entries in the tables less conceptual and more concrete:

- Can you describe how the consistency of regulation from state to state impacts the minimum requirements with respect to implementing transactive systems both local and regionally?
- When it comes to intra- and inter- jurisdictional market monitoring and oversight functions what is the best place to describe these in policy (and regulation) and who should be responsible for enforcing them?
- What types of incentives and opportunities for transactive energy systems do you think might exist fin the next 2-3 years and who do you think should be accountable for standards of performance?
- Can you explain how to ensure that the alignment of business model values across the participating entities is observable and auditable?

[5] GridWise Transactive Energy Framework Version 1.0, PNNL-22946, January 2015 (http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf)

- From a transactive energy systems perspective what do you think are the important elements to include in any standard set of definitions and structure for interfaces for X2G operations at all levels?
- Do you think we will see the interactions with buildings and facility-grids feature more prominently over time and if so what will be the drivers?
- What needs to happen in order for modeling and simulation solutions for TES to produce consistent results with each other and allow them to exchange data?
- How do you think the devices participating in transactive energy systems can support improved measurement, verification, and situational awareness of the electricity grid?
- What sort of markets and benefits might we see that transactive energy systems can support in terms of distributed devices securely integrating their actions into control schemes?
- What type of advances and services do we need to create the ability for consumer devices to support sub-cycle to long term activities in terms of markets including operations support?

Benefits and Enablers Summary

The start of each of the following sections that represents a new Track provides an overview of selected benefits and enablers from each track. Most the roadmap is comprised of tables showing the evolution of a multitude of concepts and since this involves a large amount of information this section presents a few examples of benefits and enablers for each track and presents them in the form of a summary.

The examples in this roadmap are the result of many working group meetings as well as discussions and breakouts at GWAC meetings and as such they represent the collective thinking of all those involved. There are undoubtedly additional scenarios that could be added to this roadmap and these will naturally occur over time as technology, regulation, and businesses evolve.

As the impacts of DER increase and opportunities for TES arise, it should be noted that the geographical scope of TE expands through the stages of the roadmap in each table from left to right.

Regulatory & Policy

This track describes the actions needed by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The objective of the actions in this track is to establish an environment that enables transacting parties to understand rules of engagement and compensation in addition to performance requirements (and penalties for non-performance). The actions also focus on achieving a consistency of approach across jurisdictions as much as possible to promote interoperability. The actions described may be carried out by different policy-making bodies depending on the individual jurisdictions and types of utilities.

Many of the actions described in this track support development and implementation actions described in the following Business Models and Value Realization track, and to a limited extent, the actions included in the System Design and Architecture and Physical and Cyber Technologies and Infrastructure tracks.

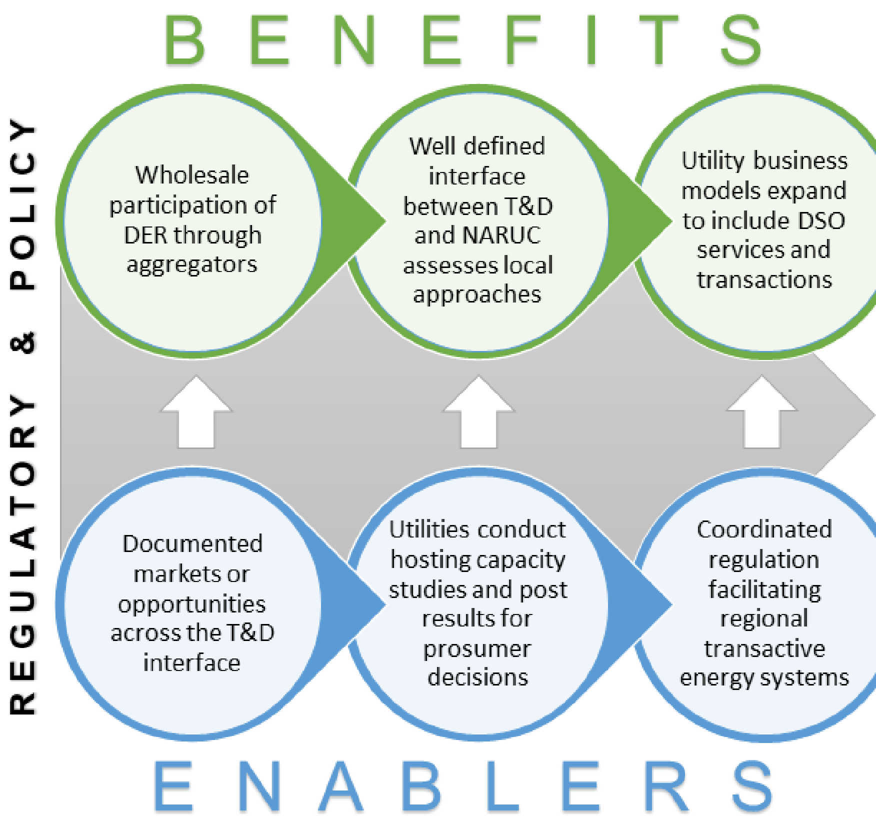

Figure 2: Example Benefits/Enablers for the Regulatory & Policy Track

Vision – what we hope to see at each stage

Describes the vision(s) we expect to be realized over time as they relate to regulatory and policy actions by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The main policy concepts are listed below.

- **RP1** - Support for retail power markets with ***non-discriminatory participation***
- **RP2** - Consistency of regulation/minimum requirements from state to state
- **RP3** - Dynamic exchange of information and value (including real-time retail tariffs) between wholesale and retail markets across the T&D interface
- **RP4** - Intra- and inter- jurisdictional market monitoring and oversight functions are described in policy (and regulation)

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
RPV01	Wholesale market transactive interactions of DER, where allowed, mainly through aggregators with no change in legacy market products and services developed for the capabilities of conventional bulk generation / system operation resources	The existence of a well-defined T&D interface from a regulatory and market perspective that allows both a distribution level market for individual participants and participation in the wholesale market for qualifying participants.	Enhancement of bulk power /wholesale market rules to align system operational needs with market-based incentives
RPV02	Questions from policy makers regarding when and how to create transactive retail markets	Several states creating regulatory support for retail energy (and derivative) markets. Analysis of regulatory differences from state to state by NARUC.	Most states have retail transactive energy market regulations with (mostly) consistent requirements and terminology.
RPV03	Transactive Exchanges available in bulk power bilateral and centralized wholesale markets, stopping at the T&D interface, with exceptions.	Evolution of new bulk power / wholesale products and services (flexibility reserves, ramping, primary frequency response, synthetic inertia) along with provisions for DER assets to provide such services	DER transactive participation in bulk power and wholesale markets based on bids and offers
RPV04	Limited use of transactive energy in distribution except for pilots and proofs of concept.	Geographic footprints of TE trades expand over larger areas of the country, creating opportunity for wide-scale power purchase agreements	End-to-end Transactive exchanges among prosumers within different layers within the distribution system as well as across the T&D interface

Enablers - elements required if the Vision is to be realized

Describes the elements that need to be in place to support and facilitate actions by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The main policy concepts are listed below.

- **RP1** - Support for retail power markets with ***non-discriminatory participation***
- **RP2** - Consistency of regulation/minimum requirements from state to state
- **RP3** - Dynamic exchange of information and value (including real-time retail tariffs) between wholesale and retail markets across the T&D interface
- **RP4** - Intra- and inter- jurisdictional market monitoring and oversight functions are described in policy (and regulation)

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
RPE01	Understand what cyber needs will be and determine cost of policies to correct equity or barrier to access issues.	Balanced need for big data and more sophisticated grid edge data analysis with consumer privacy concerns and security	Security, privacy and non-discriminatory participation are addressed in policy at all levels.
RPE02	Analysis of steps required to enable T&D integration through rate making policy	Prioritized list of inter-jurisdictional regulatory barriers to address between distribution markets.	Common DSO approaches allow consistent T&D integration.
RPE03	Documented opportunities and value proposition of markets each side of the T&D interface.	Opportunities and value proposition for markets across the T&D interface.	Minimum standards identified to allow for basic consistency of market rules between states.
RPE04	Minimal regulatory changes, but increased focus of attention including development of streamlined interconnect agreement(s).	Active regulatory involvement, and new regulations to enable TE.	Coordinated regulatory involvement opening the way for regional TE systems.
RPE05	Insights into operational cost inform how charge, billing and rate structure can cover the overhead transaction costs and identify incentives, regulations, and dynamic rate definitions.	Identify how cost and benefits are being created and distributed, and how to police bad actors where necessary; possibly through software defined rates and smart contracts.	Obligation to serve redefined for TE markets.

Results - outcomes made possible by new patterns of use

Describes the results which are important to realize the benefits that can be created by regulators and other policy makers to enable TE systems as envisioned in each of the three stages. The main policy concepts are listed below.

- **RP1** - Support for retail power markets with ***non-discriminatory participation***
- **RP2** - Consistency of regulation/minimum requirements from state to state
- **RP3** - Dynamic exchange of information and value (including real-time retail tariffs) between wholesale and retail markets across the T&D interface
- **RP4** - Intra- and inter- jurisdictional market monitoring and oversight functions are described in policy (and regulation)

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
RPR01	Lack of consumer guidelines for participation in TE systems.	Interest in development of consumer guidelines for participation in services offered by DSOs.	Consumer guidelines for participation in energy and ancillary services markets.
RPR02	Limited awareness but growing interest in TE from policymakers.	Active support from some states by allowing recovery of some approved utility costs to encourage TE.	Emergence and persistence of retail transactive energy markets.
RPR03	Rule changes to permit demand side participation in wholesale markets.	Growth of customer participation in grid management through ancillary services and reliability coordination.	Dynamic trading between DSOs and ISOs to support markets and reliability.
RPR04	Utility business models largely unchanged.	Utility business models expand to include DSO transactions and services.	DSO role is fully distinct/disaggregated from the utility role, with some DSO's merging to perform regional services.
RPR05	Quantification of cost of policies to correct equity or barrier to access issues.	Regulatory requirements for consumer privacy and security.	Common security, privacy and non-discriminatory participation policies for all DSO markets.

Benefits - how these outcomes add value

Describes the benefits that can be shaped by regulators and other policy makers as DER penetration increases through each of the three stages. The main policy concepts are listed below.

- **RP1** - Support for retail power markets with ***non-discriminatory participation***
- **RP2** - Consistency of regulation/minimum requirements from state to state
- **RP3** - Dynamic exchange of information and value (including real-time retail tariffs) between wholesale and retail markets across the T&D interface
- **RP4** - Intra- and inter- jurisdictional market monitoring and oversight functions are described in policy (and regulation)

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
RPB01	Policymakers recognize the need to address DER integration with regulatory changes.	DER provide opportunities for distribution level revenue generation through provision of grid services.	Changes to the regulatory process by some states provides tangible foundations for more change.
RPB02	Understanding of equity or barrier to access costs allows policy making to develop new models.	Regulatory definition of consumer privacy and security requirements create opportunities for service providers.	Sharing of best practices and common policies for DSO markets create opportunities for shared services and service provider growth.
RPB03	The benefit/need for demand side resources to participate in grid services is recognized.	Consumer awareness into the complications of grid operation and the benefits of participation.	Enhanced flexibility to support reliability.
RPB04	Provides confidence in TE as a viable/integration solution with potential for customer benefits.	Provides the capability to regulate (and deliver) the same grid services either side of, and across, the T&D interface.	Enables energy trading and service provision though common services and rules.
RPB05	Creates the perception of electricity as a service with value, as opposed to just "being there".	Valuation of electricity as a service creates a foundation for innovation.	Optimizes value at a personal, community and distribution system level for specific needs.
RPB06	Messaging developed in each relevant sphere for how to prepare the public and stakeholders for impact of DER, how and why to tolerate in stages 2 and 3	Benefits of TE Systems well understood in general by policy makers with respect to creating more flexibility and value	Benefits of TE Systems well understood in general by consumers with respect to creating more flexibility and value.

Business Models and Value Creation

This track focuses on the various stakeholders, their roles in TE and how their business models need to evolve for them to provide and realize value in each of the three stages. While the regulatory and policy track describes the actions policymakers need to take to establish the needed TE environment, this track focuses on the actions to assess and implement needed business model changes by various stakeholder types, recognizing that business model changes include value propositions on both supply and demand sides.

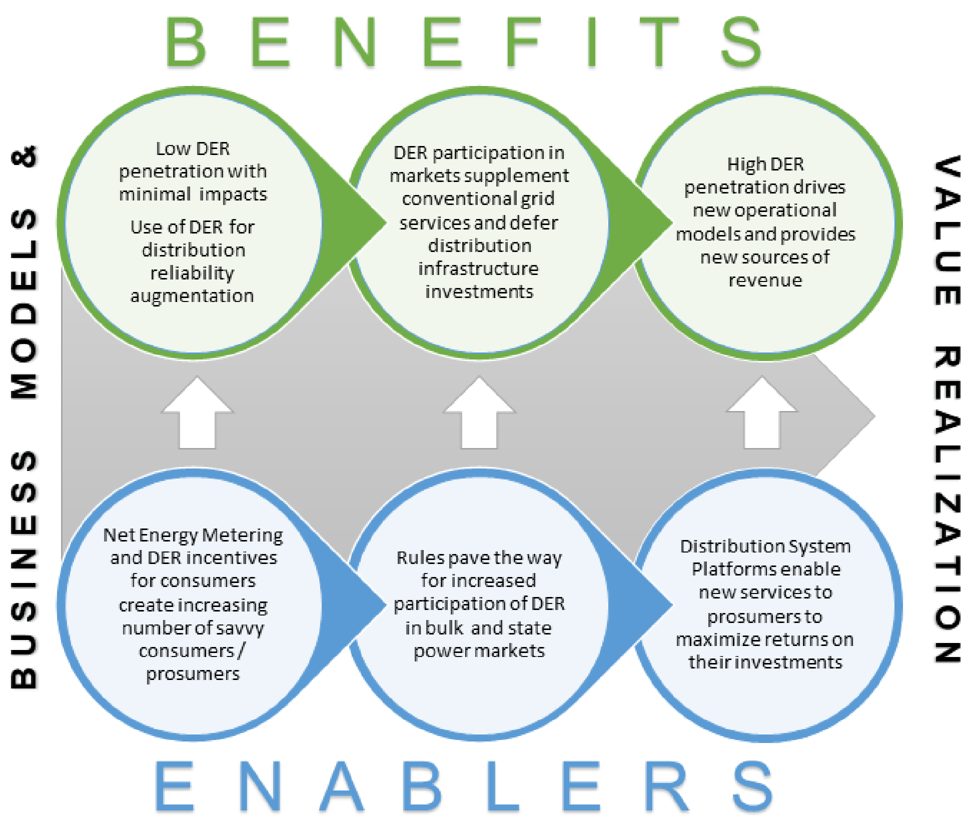

Figure 3: Example Benefits/Enablers for the Business Models & Value Realization Track

Vision – what we hope to see at each stage

Describes the vision(s) we expect to be realized over time as they relate to business model changes to enable TE systems to evolve and realize value in each of the three stages. The main business model and value concepts are listed below.

- **BM1** - Incentives and opportunities exist for all stakeholders with all ***parties accountable for standards of performance***
- **BM2** - A means exists to optimally assign value when comparing alternatives (for example wires and non-wires alternatives)
- **BM3** - Business models align values across the participating entities in an ***observable and auditable*** manner
- **BM4** - Opportunities exist for value creation (services) across multiple streams

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
BMV01	Limited use of DR for distribution capacity relief – utility DR programs	DER transactive participation based on capacity auctions primarily to defer infrastructure upgrade	Proliferation of bilateral peer-to-peer forward transactive exchanges among prosumers, including microgrids, Building Energy Management Systems (BEMS), etc.
BMV02	Main economic use of DER for load shifting or peak shaving using aggregators and direct control	Evolution of distribution level products and services that optimize value for incentivized stakeholders (phase balancing, distribution constraint relief services, etc.)	Distributed ledgers and smart contracts offer the opportunity to build new models on top of the existing infrastructure
BMV03	DER are used for local generation and reliability augmentation without use of transactive systems	Transactive exchanges across the T&D interface, mainly for large consumers/prosumers, and through intermediaries such as aggregators for smaller prosumers.	Evolution of DSOs into pseudo-balancing entities at the T&D interface while accommodating peer-to-peer bilateral exchanges across the distribution system.
BMV04	The need to develop business model simulation and valuation techniques is recognized.	Business model simulation and valuation techniques begin to be developed for TES and DER	Tools are available to model value flow to support business model simulation and valuation from different stakeholder perspectives

Enablers - elements required if the Vision is to be realized

Describes the elements that need to be in place to support and facilitate actions by various stakeholders, their roles in TE and how their business models need to evolve for them to provide and realize value in each of the three stages. The main business model and value concepts are listed below.

- **BM1** - Incentives and opportunities exist for all stakeholders with all ***parties accountable for standards of performance***
- **BM2** - A means exists to optimally assign value when comparing alternatives (for example wires and non-wires alternatives)
- **BM3** - Business models align values across the participating entities in an ***observable and auditable*** manner
- **BM4** - Opportunities exist for value creation (services) across multiple streams

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
BME01	DER penetration is sufficient to provide tangible benefits from integrated use.	Transactive exchanges across the T&D interface, enable evaluation of results and evolution of the capabilities.	Local and regional platforms for energy and service exchanges (markets).
BME02	Management of capacity and spinning reserves allow for DER participation.	Increased DER participation as capacity and spinning reserves is based on DER peer-to-peer agreements.	Peer-to-peer exchanges among prosumers, microgrids, and BEMSs contribute to additional services markets.
BME03	Aggregators and direct control make effective use of DR	Distribution level products and services that are based on DR are defined.	Incentives and opportunities exist for business models based on multiple value streams from DR.
BME04	DER opportunities available for buildings to utilize are locally handled.	External business opportunities exist for DER owners to respond to.	Business opportunities exposed through market interfaces can be created by all types of parties.
BME05	Stakeholders determine what benefits and values are monetizable and which are primarily for public good or to reduce negative externalities.	The potential for addressing spoofing and bad actors from technology and economic standpoints (and what level) is built into the business model.	New TES include modeling fair operation and game theory as part of pre-operational simulations.
BME06	Limited early interest from consumer electronics companies.	Ability for consumer electronics to interact on a broad basis locally	Appliance capabilities from consumer electronics companies allowing interaction with market signals is the norm.

Results - outcomes made possible by new patterns of use

Describes the results which are important to realize the benefits that can be created for various stakeholders, their roles in TE and how their business models need to evolve for them to provide and realize value in each of the three stages. The main business model and value concepts are listed below.

- **BM1** - Incentives and opportunities exist for all stakeholders with all ***parties accountable for standards of performance***
- **BM2** - A means exists to optimally assign value when comparing alternatives (for example wires and non-wires alternatives)
- **BM3** - Business models align values across the participating entities in an ***observable and auditable*** manner
- **BM4** - Opportunities exist for value creation (services) across multiple streams

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
BMR01	Aggregators create viable market opportunities and services.	DSOs start to become established.	"Aggregators" offer business models based on multiple value streams, move into DSO space.
BMR02	Participation is attractive for the more affluent.	Participation is attractive for many consumers.	Widespread participation drives rethink of the obligation to serve scope as all stakeholders will have more responsibility for power.
BMR03	Does not change the current business models or revenues	Implement a variety of changes and new business models.	Regulations are used to quantifiably compare wires and non-wires proposed solutions
BMR04	Several "flavors" of transactive energy systems designs.	More standardization of transactive energy systems designs.	Many sizes and types of transactive energy systems designs, based on common core principles.
BMR05	DR demonstrated for distribution capacity relief.	DER transactive energy systems demonstrate financial and reliability benefits of deferred infrastructure upgrades.	Prosumers, microgrids, buildings realize broad benefits from transactive energy through the use of DER.
BMR06	Effective use of DER for load shifting or peak shaving.	Non-utility assets actively providing phase balancing, distribution constraint relief services, etc.	Sophisticated coordinated actions integrated with financial benefits and incentives through the use of smart contracts.

Benefits - how these outcomes add value

Describes the benefits that can be created through business model evolution for various stakeholders as DER penetration increases through each of the three stages. The main business model and value concepts are listed below.

- **BM1** - Incentives and opportunities exist for all stakeholders with all ***parties accountable for standards of performance***
- **BM2** - A means exists to optimally assign value when comparing alternatives (for example wires and non-wires alternatives)
- **BM3** - Business models align values across the participating entities in an ***observable and auditable*** manner
- **BM4** - Opportunities exist for value creation (services) across multiple streams

TE Systems	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
BMB01	People start considering and looking for non-traditional solutions such as TE for DER.	Best practices start to develop and drive standards for TE.	Standards for transactive energy systems create a platform for more technical and fiscal innovation.
BMB02	No (or very limited) ability to balance supply and demand from individual distribution feeder phases to transmission circuits.	Grid resilience increases by integrating distribution and transmission actions using limited market integration across the T&D interface.	Flexible and cost effective ancillary services exist due to policy incentives for transactive integration
BMB03	DR recognized as an effective grid resource.	Transactive energy systems create multiple value streams from DR.	Transactive energy provides an engine for service innovation.
BMB04	Appearance of new players/entities in grid and market operation.	The existing utility monopoly business model and regulatory process are challenged as new business requirements drive the need for new business models.	Markets adapt to favor those who create the most value.
BMB05	Buildings and campuses find value in stand-alone solutions.	Buildings and campuses start to work together with common interests.	Parties of all types work together based on value creation and exchange as the driver.

TE Systems	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
BMB06	Insights gained into which markets, sales channel entry points and which approaches are likely to be most enduring.	Early operational cost and revenue lessons learned highlight overhead transaction costs and how to value those.	Greater opportunities for value creation through convergence of (i.e. residential, commercial, industrial etc.).
BMB07	Prosumers incentivized by centralized local level signals.	Prosumers incentivized by local and regional level signals.	Prosumers incentivized by peer to peer signals.
BMB08	DER provides ability to generate revenue.	DER creates revenue and attracts investment capital	Investment capital drives innovation in business models
BMB09	The need for simulation of business models and valuation techniques is recognized.	Business model simulation and valuation techniques begin to be developed for TES and DER	Tools are available to model value flow and business model simulation from different stakeholder perspectives

System Design and Architecture

This track focuses on system design and architecture actions necessary to support each stage specifically dealing with information interoperability to support TE valuation, and operation and control aspects to understand and manage the impacts on the electric grid. This track depends on the business model to define required information exchange between TE parties in content and timing. This is where each stakeholder needs to develop or understand their "as-is" architecture and their "to-be" architecture, then develop a set of transitional states to get them there and transition between stages

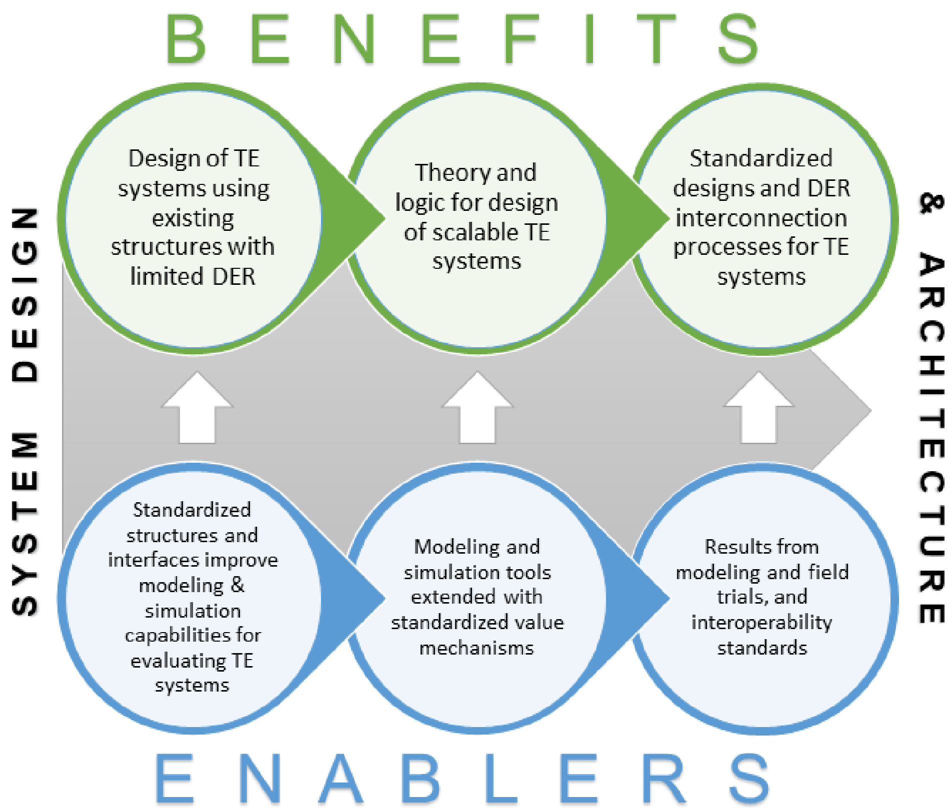

Figure 4: Example Benefits/Enablers for the System Design & Architecture Track

Vision – what we hope to see at each stage

Describes the vision(s) we expect to be realized over time as they relate to design and architecture activities necessary to support each stage specifically dealing with information interoperability to support TE valuation, and operation and control aspects to understand and manage the impacts on the electric grid. The main design and architecture concepts are listed below.

- **DA1** - A standard set of definitions and structure develops for interface structure for X2G operations at all levels
- **DA2** - Transition from centralized to decentralized based on ***highly coordinated self-optimization***
- **DA3** - ***Reliability and control*** are assigned value when integrated into all TE systems that interact with the grid
- **DA4** - Buildings and facility-grids feature more prominently over time
- **DA5** - Modeling and simulation solutions for TES produce consistent results with each other and can exchange data

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
DAV01	The grid consists of transmission and distribution with interfaces driven by local interconnection requirements.	The grid consists of a collection of independent or semi-independent systems operating in a coordinated way.	Standardized interfaces create reusability of applications at all levels within the grid.
DAV02	Characterized by centralized distribution control by utilities	Mix of centralized and distributed control still largely using centralized optimization across service territory with utility beginning to act as DSO	Distributed system operations and controls coordinated via DSO with all stakeholders across the region.
DAV03	Local management of transactive systems used to optimize behind the meter buildings, campus, and microgrid value.	DER at connected buildings interact with the grid, enabled by transactive energy systems	Distributed optimization of buildings and other DER facilities support reliability and resilience.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
DAV04	Local devices respond to grid events on a deterministic basis.	Local device behavior is a mix of deterministic and stochastic requiring modeling and simulation	Stochastic optimization[6] is employed as a means of more accurately accounting for uncertainties in interactions (and simulations) across a large number of devices and participants

Enablers - elements required if the Vision is to be realized

Describes the elements that need to be in place to support and facilitate system design and architecture actions necessary to support each stage specifically dealing with information interoperability to support TE valuation, and operation and control aspects to understand and manage the impacts on the electric grid. The main design and architecture concepts are listed below.

- **DA1** - A standard set of definitions and structure develops for interface structure for X2G operations at all levels
- **DA2** - Transition from centralized to decentralized based on ***highly coordinated self-optimization***
- **DA3** - ***Reliability and control*** are assigned value when integrated into all TE systems that interact with the grid
- **DA4** - Buildings and facility-grids feature more prominently over time
- **DA5** - Modeling and simulation solutions for TES produce consistent results with each other and can exchange data

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
DAE01	Pilot applications utilize limited number of pre-qualified partners with proprietary solutions.	Standardized models of transactive system nodes allow more partners with increasingly open solutions and exchanges of value.	Broadly applied TE systems optimize locally but coordinate actions by valuing control as a key parameter.

[6] Stochastic optimization refers to the minimization (or maximization) of a function in the presence of randomness in the optimization process. It should include financial risk management tools and approaches.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
DAE02	Centralized control schemes.	Creation of early DSOs and distributed control schemes.	Building Management Systems, microgrids, and other devices include support for coordination with distributed control schemes.
DAE03	Local interconnection requirements enable DER connections.	Common interconnection requirements enable participants to operate more easily in multiple locales.	Grid interfaces are standardized using specific required elements.
DAE04	Quicker, more efficient, distribution modeling and forecasting techniques	Modeling and simulation of bidirectional power and DER events.	Modeling tools available for microgrids provide for federated modeling capabilities.
DAE05	Interoperability addressed through definition of basic information exchanges between transactive nodes	General models of transactive nodes defined including interfaces between nodes and between nodes and other elements including DERs	Standards developed supporting general models of transactive nodes and low-cost integration of transactive nodes and components
DAE06	DER implementations start to cause design modifications to existing infrastructure	Wires and non-wires designs are developed to adapt to future scenarios	Increased islanding capability supported by DER creates opportunities for TES at scale
DAE07	The integration of DER helps popularize campus microgrids.	Microgrids created from the distribution grid or installed as an overbuild network with new wires	Coordinating microgrids is a central part of managing distribution grids

Results - outcomes made possible by new patterns of use

Describes the results which are important to realize system design and architecture changes necessary to support evolution at each stage; specifically dealing with information interoperability to support TE valuation, and operation and control aspects to understand and manage the impacts on the electric grid. The main design and architecture concepts are listed below.

- **DA1** - A standard set of definitions and structure develops for interface structure for X2G operations at all levels
- **DA2** - Transition from centralized to decentralized based on ***highly coordinated self-optimization***
- **DA3** - ***Reliability and control*** are assigned value when integrated into all TE systems that interact with the grid
- **DA4** - Buildings and facility-grids feature more prominently over time
- **DA5** - Modeling and simulation solutions for TES produce consistent results with each other and can exchange data

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
DAR01	Local reliability and control managed by utilities.	DSOs appear in a few states/service territories, enabling DER to provide reliability and control benefits.	Significant numbers of DSOs result in highly coordinated self-optimization for buildings and local grids (campuses, facilities).
DAR02	Technical capabilities of TES proven at local level.	Increased scale of TES includes diverse value systems that prove the optimization methods.	Large scale deployments monetize control as a key parameter to be optimized with other goals.
DAR03	Raising device and system interoperability awareness drives interest in interoperability measurement.	Raising of interoperability awareness for system modeling and simulation capabilities (co-simulation data exchange).	Interoperability of policy and regulation. Certification for interoperability maturity.
DAR04	Support for transactive systems for campuses, microgrids and buildings	Support for transactive systems for dis-contiguous sites.	Support for transactive systems in most system and market designs.
DAR05	Implementation of CVR/VVO and phase balancing based on central control.	Bidirectional power and voltage management by coordinating DER activities and ancillary services through transactive energy systems.	Federated modeling capabilities based on the ubiquity of transactive energy systems to create value and flexibility.
DAR06	System designed for peak load, lower load factors.	Transactive energy systems permit designs for higher load factors and deferred upgrades.	New designs incorporate transactive energy systems as de facto elements.

Benefits - how these outcomes add value

Describes the system design and architecture benefits that can be created as DER penetration increases through each of the three stages. The main design and architecture concepts are listed below.

- **DA1** - A standard set of definitions and structure develops for interface structure for X2G operations at all levels
- **DA2** - Transition from centralized to decentralized based on ***highly coordinated self-optimization***
- **DA3** - ***Reliability and control*** are assigned value when integrated into all TE systems that interact with the grid
- **DA4** - Buildings and facility-grids feature more prominently over time
- **DA5** - Modeling and simulation solutions for TES produce consistent results with each other and can exchange data

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
DAB01	Recognition that proprietary solutions produce local benefits but have limited coordination capabilities.	Standardized definitions and structure develop for interface that include value, driven by TES coordination.	Including value in grid interfaces and valuing control explicitly leads to less congestion.
DAB02	Predictable performance supports centralized architecture.	Hybrid of deterministic and stochastic behavior drives new modeling and simulation capabilities.	Improved modeling and simulation capabilities support improved designs that use stochastic optimization to reduce uncertainties.
DAB03	Increased awareness of TES as a solution for both local optimization and community coordination.	Lessons learned from increasing numbers of TES that coordinate remote sites and organizations with each other.	Grid architecture becomes much more flexible as it includes and coordinates many distributed TES.
DAB04	Quick and affordable ways to get consumers interacting with the grid.	Improved modeling creates opportunities for much more decentralized and customer-driven solutions.	Coordination between stakeholders using TES creates market opportunities beyond the grid.
DAB05	Does not require changes to the current U.S. structure of the utility industry (FERC, PUCs, ISOs/RTOs, munis, coops, IOUs, vendors)	Acts as a catalyst for design change across the T&D boundary.	Provides a foundation for new designs for system architecture and energy services.
DAB06	Increasing interest in interoperability driven by need to integrate DER.	DER interface standardization reduces the need to modify existing systems to interoperate with them	Reduced integration cost for DER decreases costs to deploy and integrate new TE systems.

Physical and Cyber Technologies and Infrastructure

This track focuses on the changing Cyber-Physical needs and required actions through the progression of the three stages. This track addresses the technical layers of the GWAC Stack and the physical layers of the Control Abstraction Stack[7]. It includes the activities aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electric grid. This track depends on the information exchange requirements considered in the system design and architecture track to ensure the ability to exchange information in support of transactions without detrimentally affecting the reliability of the electrical network.

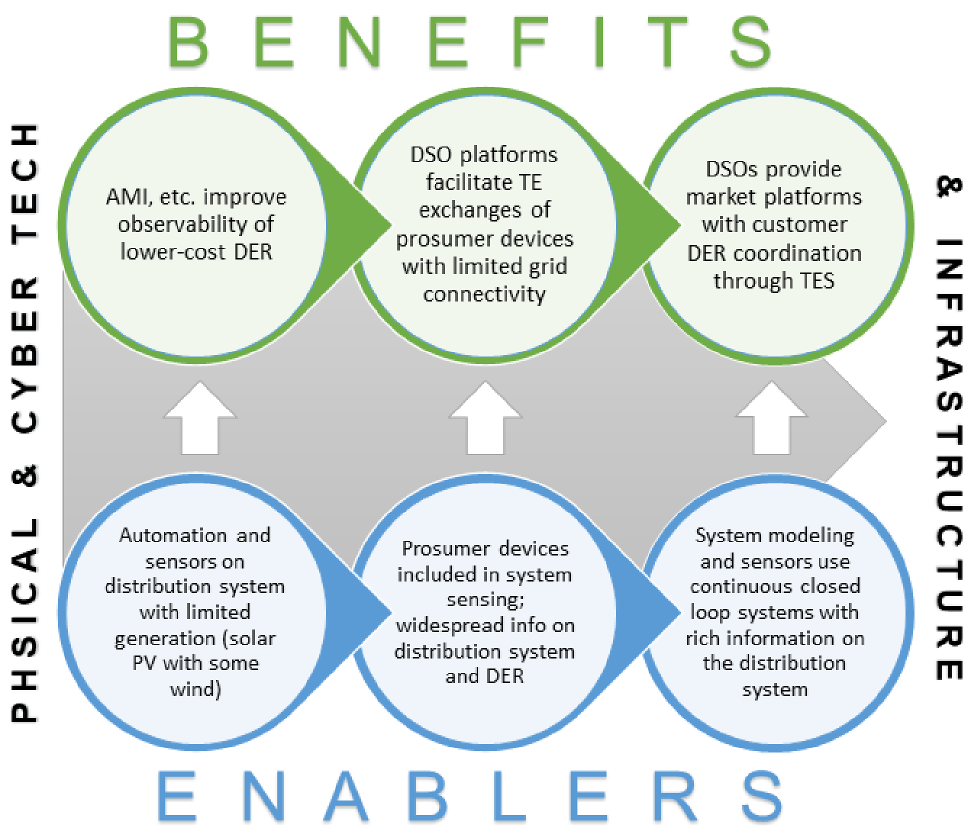

Figure 5: Example Benefits/Enablers for the Physical & Cyber Technologies & Infrastructure Track

[7] Control abstraction is the abstraction of actions. The Control Abstraction Stack referenced in GWAC's TE Framework helps put the concept of cyber-physical systems in context for TE management.

Vision – what we hope to see at each stage

Describes the vision(s) we expect to be realized over time as they relate to physical and cyber technologies and infrastructure changes aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electric grid. The main physical and cyber technologies and infrastructure concepts are listed below

- **PC1** - Improved measurement, verification, and situational awareness
- **PC2** - Affordability of devices and communications enables ***scalable, adaptable, and extensible***[8] deployment
- **PC3** - Distributed devices securely integrated into control schemes
- **PC4** - Ability for consumer devices to support sub-cycle to long term activities (markets/operations)
- **PC5** – Explicit, well-defined, trust models that define identity, authentication, service level agreements, and privacy need to be built into all TE systems.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
PCV01	Proliferation of Advanced Metering Infrastructure (AMI) or other measures to improve distribution system operator observability into DER	Evolution of DSOs with distributed system platforms primarily utilizing DERMS and ADMS, and facilitating new transactive exchanges	DSO construct realized at scale with distribution market platforms and broad awareness of impacts across the T&D interface
PCV02	Deployment of DMS and ADMS systems by most utilities. Limited circuit switching capability.	Enhancement and evolution of DMS/ADMS for better situational awareness and control. Automated switching for more distribution circuits.	Distribution state estimators and phasor measurement systems in use for distribution systems and used in transactive energy system optimization
PCV03	Cost of smart devices for use by utilities continues to drop, driving broad deployment	Proliferation of low cost prosumer devices leading to improved local control systems and limited connectivity to grid systems	Customer and facility devices and control systems coordinate with utilities and DSOs through transactive energy systems

[8] Items in ***bolded italics*** represent condensed encapsulations of the TE principles described in Section 3.3 of the TE Framework

Enablers - elements required if the Vision is to be realized

Describes the elements that need to be in place to support and facilitate activities aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electric grid. The main physical and cyber technologies and infrastructure concepts are listed below

- **PC1** - Improved measurement, verification, and situational awareness
- **PC2** - Affordability of devices and communications enables ***scalable, adaptable, and extensible*** deployment
- **PC3** - Distributed devices securely integrated into control schemes
- **PC4** - Ability for consumer devices to support sub-cycle to long term activities (markets/operations)
- **PC5 –** Explicit, well defined, trust models that define identity, authentication, service level agreements, and privacy need to be built into all TE systems.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
PCE01	Automation and utility sensors established on the distribution system.	Prosumers and non-utility devices are included in system sensing.	System is continuously monitored and modeled.
PCE02	Devices that can provide load reduction with some load shifting	Interactive devices that can perform load reduction and shifting with some load increases	Fully integrated cyber-physical system for DER that provides balancing of distributed supply and demand
PCE03	Limited generation on the distribution system. Mostly solar with some wind.	Widespread generation on the distribution system. Mostly solar with some wind. Storage benefits being realized.	Widespread generation and storage on the distribution system.
PCE04	Integration, albeit limited, of supply and demand incorporating DER on the distribution system.	Device addressability that creates more connected opportunities without the need for excessive layers of communication and control.	Commercially available open platforms with main functions of DSO being standardized across regulatory jurisdictions and incorporating standards-based requirements.
PCE05	Inverters provide basic DC/AC conversion	Ability of inverters to ride though frequency and voltage excursions	Use of inverters to provide artificial inertia and regulation services.
PCE06	Affordable, reliable, wireless data infrastructure with secure communications	Quicker, cheaper, and more secure direct communication paths.	Trust models provide identity, authentication, service level agreements, and privacy
PCE07	DER testing and certification established for standards compliance.	Increased use of simulation as an enabler for testing.	Increased interoperability as a result of simulation and testing.

Results - outcomes made possible by new patterns of use

Describes the results aimed at the electrically connected network and the communications networks that are necessary to monitor and control the electric grid. The main physical and cyber technologies and infrastructure concepts are listed below

- **PC1** - Improved measurement, verification, and situational awareness
- **PC2** - Affordability of devices and communications enables ***scalable, adaptable, and extensible*** deployment
- **PC3** - Distributed devices securely integrated into control schemes
- **PC4** - Ability for consumer devices to support sub-cycle to long term activities (markets/operations)
- **PC5 –** Explicit, well defined, trust models that define identity, authentication, service level agreements, and privacy need to be built into all TE systems.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
PCR01	Improved visibility of phase balancing and voltage variations.	Changes to system behavior can be monitored as DER penetration increases.	System models can be frequently updated with a closed loop system
PCR02	Familiarity with DMS provides visibility and control capabilities with limited switching capability.	DMS/ADMS/DERMS provides improved situational awareness and control with automated switching.	The ability to frequently model the distribution system on demand.
PCR03	Load reduction with some load shifting	Load reduction and shifting with some load increases	Balanced distributed supply and demand
PCR04	Inverters start to interact with the distribution system.	Inverters able to provide support over broader range of frequency and voltage.	Inverters providing artificial inertia and regulation services.
PCR05	Consumer and building owner awareness of commercially available DER.	Consumer and building owner focus on trust models and service level agreements.	trust models and service level agreements

Benefits - how these outcomes add value

Describes the benefits that can be created for the electrically connected network and the communications networks that are necessary to monitor and control the electric grid as DER penetration increases through each of the three stages. The main physical and cyber technologies and infrastructure concepts are listed below

- **PC1** - Improved measurement, verification, and situational awareness
- **PC2** - Affordability of devices and communications enables ***scalable, adaptable, and extensible*** deployment
- **PC3** - Distributed devices securely integrated into control schemes
- **PC4** - Ability for consumer devices to support sub-cycle to long term activities (markets/operations)
- **PC5 –** Explicit, well defined, trust models that define identity, authentication, service level agreements, and privacy need to be built into all TE systems.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
PCB01	Improved visibility of phase balancing and voltage variations.	Changes to system behavior can be monitored as DER penetration increases.	System models can be frequently updated with a closed loop system
PCB02	Familiarity with DMS provides visibility and control capabilities with limited switching capability.	DMS/ADMS/DERMS provides improved situational awareness and control with automated switching.	The ability to model the distribution system frequently/on demand.
PCB03	DER observability and behavior well understood/developed.	High degree of overall distribution observability with low latency.	Empirical optimization of market exchanges across the T&D interface.
PCB04	Load reduction with some load shifting	Load reduction and shifting with some load increases	Balanced distributed supply and demand
PCB05	Inverters start to interact with the distribution system.	Inverters able to provide support over broader range of frequency and voltage.	Inverters providing artificial inertia and regulation services.
PCB06	Basis established for common communications paths/protocols.	Transactive energy systems make use of common communications paths/protocols.	Transactive energy systems included in cost/benefit studies for future communications infrastructure.
PCB07	Increased use of microgrids and storage provide	Increased deployments of microgrids and storage causes	Microgrids and storage are increasingly utilized for grid control.

Reference	Stage 1 *Persistently Demonstrated*	Stage 2 *Broadly Applied*	Stage 3 *At Scale*
	opportunities for resilience pilots.	acceleration of new technologies.	
PCB08	Learning how to manage voltage impacts as acceptance of local PV increases	Reduced losses due to increased solar panel efficiencies	Solar PV and energy storage used to more efficiently generate power with fewer losses
PCB09	DER standardization provides more choice in products.	Improved DER integration decreases costs to deploy and integrate new standards compliant technologies.	Standardization ensures that today's technology can interface with future technologies.

References

Distribution Systems in a High Distributed Energy Resources Future: Planning, Market Design, Operation and Oversight, LBNL-1003797, October 2015, (https://emp.lbl.gov/sites/all/files/lbnl-1003797.pdf)

GridWise Transactive Energy Framework Version 1.0, PNNL-22946, January 2015 (http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf)

Appendix A - Core Concepts

This appendix states the fundamental concepts[9] in as timeless (stage-free) a manner as possible for each track of the roadmap. **Note**: items in ***bolded italics*** represent condensed encapsulations of the TE principles described in Section 3.3 of the TE Framework document[10].

Regulatory and Policy

- **RP1** - Support for retail power markets with ***non-discriminatory participation***[11]
- **RP2** - Consistency of regulation/minimum requirements from state to state
- **RP3** - Dynamic exchange of information and value (including real-time retail tariffs) between wholesale and retail markets across the T&D interface
- **RP4** - Intra- and inter- jurisdictional market monitoring and oversight functions are described in policy (and regulation)

Business Models and Value Realization

- **BM1** - Incentives and opportunities exist for all stakeholders with all ***parties accountable for standards of performance***[12]
- **BM2** - A means exists to optimally assign value when comparing alternatives (for example wires and non-wires alternatives)
- **BM3** - Business models align values across the participating entities in an ***observable and auditable***[13] manner
- **BM4** - Opportunities exist for value creation (services) across multiple streams

System Design and Architecture

- **DA1** - A standard set of definitions and interface structures based on Laminar Decomposition for all X2G[14] operations, for transactive exchanges within and across all structural layers

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[9] The concepts presented in this overview document may change by the time the roadmap is finalized

[10] GridWise Transactive Energy Framework Version 1.0, PNNL-22946, January 2015 (http://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf)

[11] **TE Principle:** Transactive energy systems should provide for non-discriminatory participation by qualified participants

[12] **TE Principle:** Transacting parties are accountable for standards of performance

[13] **TE Principle:** Transactive energy systems should be observable and auditable at interfaces

[14] X2G is shorthand for anything-to-grid. This represents the boundary between two controlled systems.

- **DA2** - Transition from centralized to decentralized based on ***highly coordinated self-optimization***[15]
- **DA3** - ***Reliability and control***[16] are assigned value when integrated into all TE systems that interact with the grid
- **DA4** - Buildings and facility-grids feature more prominently over time
- **DA5** - Modeling and simulation solutions for TES produce consistent results with each other and can exchange data

Physical and Cyber Technologies and Infrastructure

- **PC1** - Improved measurement, verification, and situational awareness
- **PC2** - Affordability of devices and communications enables ***scalable, adaptable, and extensible***[17] deployment
- **PC3** - Distributed devices securely integrated into control schemes
- **PC4** - Ability for consumer devices to support sub-cycle to long-term activities (markets/operations)
- **PC5 –** Explicit, well-defined, trust models that define identity, authentication, service-level agreements, and privacy need to be built into all TE systems.

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[15] **TE Principle:** Transactive energy systems implement some form of highly coordinated self-optimization

[16] **TE Principle:** Transactive energy systems should maintain system reliability and control while enabling optimal integration of renewable and DERs

[17] **TE Principle:** Transactive energy systems should be scalable, adaptable, and extensible across a number of devices, participants, and geographic extents